The benefit of management policy of Seoul on airborne particulate matter: An application of contingent valuation

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Abstract

There is an increasing concern on particulate matter (PM) management in Seoul. The annual mean PM concentration of Seoul is far higher than the World Health Organization guideline and its decreasing rate has been slowed since 2012. Seoul Metropolitan Government has made various efforts to solve the problem. In particular, after an open forum held in June 2017, the Ten Measures for Fine Particles were established. Since the management of fine particles would enforce a huge budget (annual mean of 146 million US dollar) it requires a legitimate validation by the benefit analysis. This paper aims to estimate the benefit of the management policy of Seoul on airborne particulate matter. The benefit is estimated by the contingent valuation method. The estimation by the Spike model shows that the annual willingness to pay (WTP) per household for the management of airborne particulate matter is 126 US dollar (or 138,107 Korean won) (95% confidence interval of 114 to 137 US dollar). The applications of the other statistical models are also analyzed. Considering the total number of households, annual benefit of the management policy of Seoul on airborne particulate matter is 492 million US dollar annually (95% confidence interval of 446 to 537 million US dollar). A simple comparison shows that the benefit of the management of airborne particulate matter in Seoul is 3~4 times higher than the incurred expense.

Key words

Air pollution; Contingent valuation; Particulate matter; Willingness to pay

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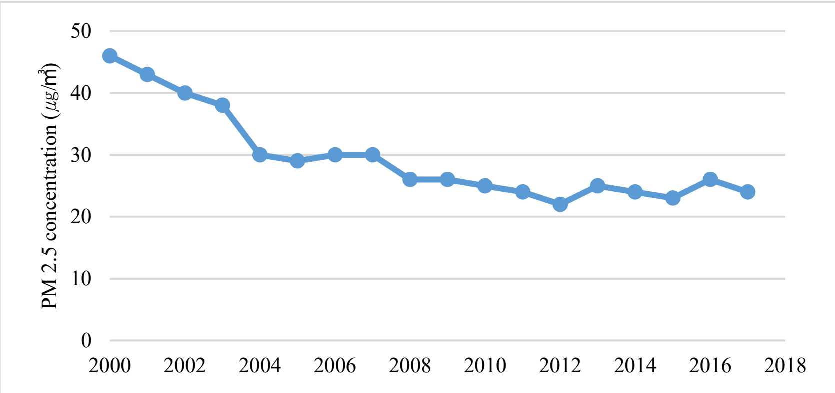
1. Introduction

Air pollution is one of the major environmental hazards responsible for death and illness worldwide. In particular, ambient air pollution is the 5th leading cause of death after high systolic blood pressure, smoking, high fasting plasma glucose, and high total cholesterol (Cohen et al., 2017). Particulate matter whose diameter is less than 2.5 micrometer (PM 2.5) has the highest influence on the health condition (WHO, 2015). For instance, a total of 4.2 million deaths were attributed to PM 2.5 worldwide in 2015 (Cohen et al., 2017).

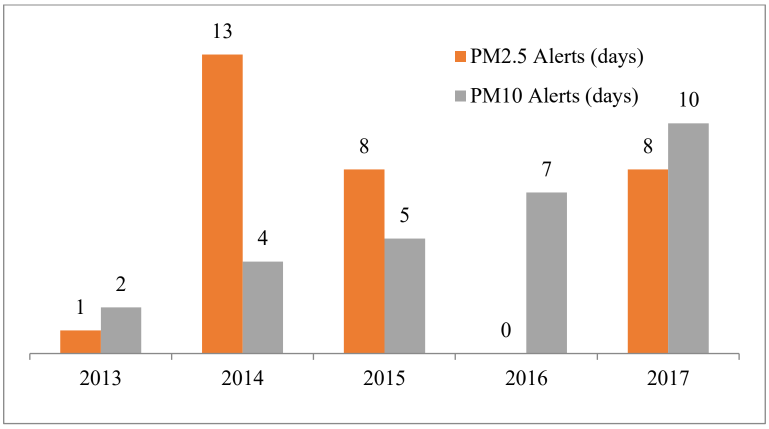
There is an increasing concern on PM 2.5 management in Seoul. The annual mean PM 2.5 concentration of Seoul (26 $\mu g/m^3$ in 2017) is 2.6 times higher than the WHO guideline (WHO, 2005). The decreasing rate of PM 2.5 concentration of Seoul has been slowed and stalled since 2012, as shown in Figure 1. The main reasons are transboundary inflows mainly from China, secondary formation of PM 2.5, and unregulated emission sources such as diesel passenger cars (SMG, 2016; Hwang, 2018). The number of high concentration episodes has been gradually increased recently, as shown in Figure 2. The total premature deaths due to PM 2.5 were 1,763 people in 2015 (Han et al., 2018). Put differently, 19.3 people per 100 thousand are died of PM 2.5 annually in Seoul.



Data source: Air Korea (http://airkorea.or.kr)

Note: WHO recommendation (annual mean of 10㎍/㎥), Korea National standards (annual mean of 15㎍/㎥)

Figure 1 PM 2.5 concentration of Seoul



Data source: Air Korea (http://airkorea.or.kr)

Note: PM 2.5 (PM 10, respectively) alert is issued when its hourly mean concentration is higher than 90 $\mu g/m^3$ (150 $\mu g/m^3$) for 2 consecutive hours.

Figure 2 PM alerts of Seoul

Seoul Metropolitan Government (SMG) has made various efforts to solve the particulate matter problem. In particular, after an open forum held in June 2017, the Ten Measures for Fine Particles were established. Among others, PM 2.5 emergency scheme and a new urban access regulation (e.g., designated areas where the most polluting vehicles are regulated) have been introduced since 2017. SMG has a long-term goal of PM 2.5 concentration, 15$\mu g/m^3$ in 2025 (Hwang, 2018).

Since the management of fine particles would enforce a huge budget it requires a legitimate validation by the benefit analysis (Amann et al., 2011; EPA, 2011). For instance, the total budget of the program, Ten Measures for Fine Particles, is about 583 million US dollar until 2020 (for 4 years) (Hwang, 2018). However, there is no benefit analysis on this issue yet in the literature.

In addition, economic analysis on the PM management would help to cooperate with other municipalities and neighboring countries. Cooperation between East Asian countries on transboundary air pollution is still limited to scientific analysis and exchange of information (Reimann, 2012; Otsuka, 2018). Based on economic analysis along with scientific analysis, East Asian countries may be able to set up effective plans for the cooperation with other bodies.

This paper aims to estimate the benefit of the management policy of Seoul on airborne particulate matter. The benefit is estimated by the contingent valuation (CV) method, which is an important tool used for the valuation of products or services that are not traded in the market (Carson, 1991; Arrow et al., 1993; Carson and Hanemann, 2005). The benefit of environmental policies has been widely estimated by the CV method (e.g., Brookshire et al., 1982; Kwak and Russell, 1994; Carson et al., 2003).

The structure of this paper is as follows. Section 2 reviews literature on the benefit of the fine particles management policies. The model and methods are shown in Section 3. Section 4 presents the main results and Section 5 concludes.

2. Theoretical background and literature review

The cost of airborne particulate matter can be divided into the market cost and the non-market cost. The market cost is the effects of particulate matter on goods or services traded in the market. It includes the expenses on the health insurance, the reduction in labor productivity due to decreasing working days, and the damages in crop yields and industrial production. The non-market cost is the effects on goods or services which are not traded in the market. It includes the influence on the health condition (e.g., premature death), the aesthetic effects (e.g., reduced visibility), and the ecological disturbances.

On the one hand, the benefit of the management policies on airborne particulate matter can be defined by the reduction in the damage cost by the administration of the management policies as shown in Equation (1). That is, the approach is to estimate the damage cost directly on each scenario and then calculate the difference in the costs.

$$B = C_{\text{w/o policy}} - C_{\text{policy}} \quad (1)$$

where, B and C refer to the benefit and cost, respectively, and the subscripts, 'policy' and 'w/o policy,' refer to the cases when the policy is administered and not administered, respectively.

OECD (2016) forecasts the emission of the air pollutants along with its concentrations and physical effects using the GAINS model (IIASA, 2009). The market cost is estimated by a CGE model while the non-market cost is evaluated from the valuation method (i.e., 'benefit transfer').[1] The market cost of the member countries due to air pollution in 2060 is projected to be 0.5% of the income on average while the non-market cost is projected to be 5% of the income. EPA (2011) estimates the cost and benefit of the policies on air pollution after the amendment of the Clean Air Act. The emission of air pollutants along with the concentrations and physical effects are forecasted in the cases of when the Clean Air Act is in effect and when is not. The benefit of the Clean Air Act is calculated using the valuation method (i.e., 'benefit transfer') and is compared with the policy cost. The results show that the cost for the air quality management policies according to the Clean Air Act amounts to 65 billion dollars while the benefit due to the improved air quality is estimated to be 2 trillion dollars. Holland (2014) investigates the cost and benefit of the air pollution policies of the EU. The study forecasts the emission, concentration and physical effects using the GAINS model, and estimates the benefit using the valuation method (i.e., 'benefit transfer'). The results show that the benefit of the air pollution policies are 12 to 42 times larger than the policy cost. World Bank and IHME (2016) estimates the damage cost of air pollution by countries using the Global Burden of Diseases (GBD) database (Cohen et al., 2017). The

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[1] Benefit transfer is one of the valuation methods, which applies the values (e.g., value of statistical life) surveyed in the literature for the calculation of the non-market cost (Tietenberg and Lewis, 2012).

monetization of the physical effects is based on the valuation method (i.e., 'benefit transfer'). Applying the similar methods, OECD (2014) estimates the damage cost for the public health due to the transportations in the member countries as well as China and India using the valuation method. WHO Europe and the OECD (2015) estimates the damage cost of air pollution in the EU member countries, and AEA (2011) analyzes the benefit and cost according to the scenario of the Gothenburg Protocol.

Another approach to estimate the benefit is to calculate willingness to pay (WTP) of the people on the management policy. Although the results from the two approaches should coincide in theory, they might be different from each other because there is a bias related with the methodology on the WTP survey (Arrow et al., 1994; Carson and Hanemann, 2005) and uncertainty and errors in measuring the damage cost (OECD, 2016).

While many studies have estimated WTP for the abatement of air pollution in general, only a few have been conducted in South Korea, and even fewer with respect to PM2.5 specifically (e.g., Yu et al., 2003; Lee et al., 2004; Cho et al., 2006; Hong and Oh, 2006; Kwon and Seo, 2010).[2] We only present some recent studies focusing on PM2.5 issues of Seoul. Among others, applying regression models, Lee et al. (2011) find that Seoul citizens are willing to pay a burden of 20.2 US dollar (13.9 US dollar, respectively) per month on average to reduce the risk of premature mortality from airborne particulate matter by 5/10,000 (by 1/10,000, respectively). Kim et al. (2018), on the other hand, apply the contingent valuation method with the spike model and find that South Korean households living in urban areas are willing to pay 5 US dollar a year for the reduction of high PM2.5 concentration episodes by half. The results of Kim et al. (2018) are so small compared to the literature. For instance, although surveyed in Chinese cities, applying the probit and interval regression models, Wei and Wu (2016) estimate that Jingjinji Metropolitan Region residents (which includes Beijing, Tianjin, and Hubei) are willing to pay 91 US dollar (or 602 Yuan) per person a year, which is equivalent to almost 1% of the GDP per capita for the reduction of PM concentrations within the region. Yin et al. (2018) estimate the WTP of Beijing citizens to avoid health risks, along with other psychological effects, caused by air pollution using a random forest model. The results are that annual WTP for the reduced health effect is

[2] Yu et al. (2003) estimate WTP to avoid the ecological effects due to air pollution in Seoul by a multinomial logit model. A monthly average of WTP per household is estimated about 50 US dollar. Lee et al. (2004) classify the benefit of air quality improvements in the metropolitan area of Seoul into six categories including death, illness, and global warming and estimate WTP of each category. A monthly average of WTP per household is estimated about 15 US dollar by the logit model using the triple-bounded dichotomous choice format CVM. Cho et al. (2006) estimate WTP of the citizen on the health effects due to the improved air quality in the metropolitan area of Seoul. The WTP is estimated using the multinomial logit model based on the survey using the conjoint analysis. The estimated yearly WTP per household is about 35 US dollar. Hong and Oh (2006) estimate WTP of the citizen on the improved air quality in the subway. They employ the simultaneous equation model based on a recursive system to estimate WTP. The results show that the yearly WTP per household is about 5 US dollar. Kwon and Seo (2010) study WTP of the improvement on the air quality of Seoul using CVM. The study introduces the Weibull survival function and estimates a monthly average of about 1 US dollar.

207 US dollar (or 1,370 Yuan), and WTP for the improved psychological impacts is 143 US dollar (or 946 Yuan).

As mentioned above, not many studies have attempted to estimate the WTP for reduced PM2.5 levels in South Korea. This study is unique in that it attempts to estimate the WTP of Seoul citizens for the implementation of specific PM2.5 reduction policies, such as urban access regulations and shutdown of industrial emissions sources. Unlike the literature, we estimated WTP of households focusing on the airborne particulate matter among other air pollutants. This is important because PM 2.5 is much more harmful than other air pollutants (WHO, 2015; Cohen et al., 2017). We also applied various statistical models for the estimation of WTP to investigate the sensitivity of WTP to the models used. Compared to the previous studies (Lee et al., 2011; Kim et al., 2018), the current paper is different in that it provides additional materials (such as pictures showing differences in visibility depending on PM2.5 levels, changes in the rate of mortality for different concentrations, and payment cards) for the survey respondents to consider and make more informed decisions.

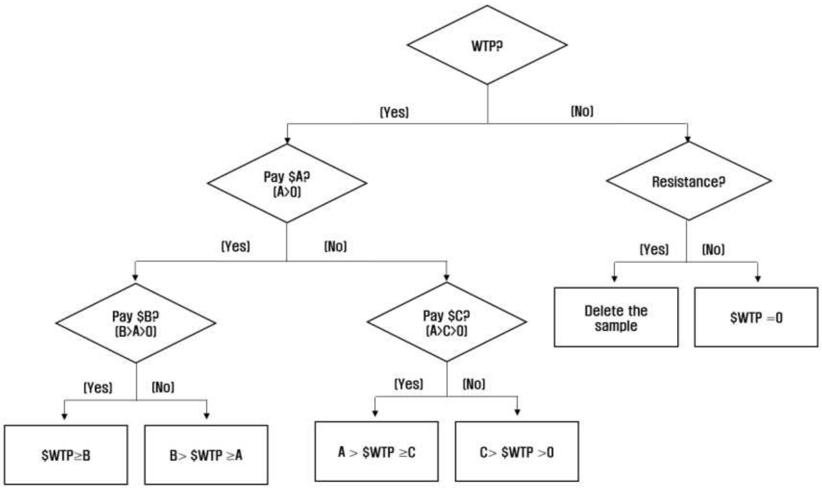
3. Methods

3.1. Survey design and scenarios

To estimate the benefit of the air quality management policy of Seoul, this paper constructs a virtual market and applies a CV method that inquires WTP about newly introduced products. The process of WTP analysis and its layout is as follows. First, questionnaires were made after a review by experts. 51 households in Seoul were chosen by a random proportional allocation for a preliminary survey. Based on the preliminary survey, the questionnaires for the main survey was finalized as well as the initial bid (See Appendix A). The main survey was conducted on 551 households in Seoul chosen by a random proportional allocation (sampling error 4.0%p at 95% confidence level). The survey was conducted during June 2018 and the survey method was personal interview. For more on the characteristics of respondents, see Appendix B.

The dichotomous choice question format was used to ask WTP as suggested by Arrow et al. (1993) and Carson and Hanemann (2005). The dichotomous choice question format has the single-, double- and triple-bounded dichotomous choice formats depending on the number of questions. The single-bounded dichotomous choice format is a method that estimates WTP of respondents from a single response. The format has an advantage that imitates a similar situation when a consumer purchases a product. However, it requires a large pool of samples and a complex econometric model to acquire a statistically significant estimation (KDI, 2012). Moreover, dichotomous choice question formats of a triple bound or more have the reference effect that WTP can be determined by the initial bid after multiple questions. The double-bounded dichotomous choice format has an advantage to get more information about WTP from two dichotomous choices and is known to be statistically effective than the single-bounded format (Kwon and Seo, 2010). In this paper, the double-bounded dichotomous choice format is used for the estimation of WTP to improve the statistical efficiency of the estimate and prevent the reference effect due to subsequent questions.

The design of the double-bounded dichotomous choice format is described in the following figure. Two scenarios regarding the air quality management were presented to the respondents: One was the scenario that would maintain the current condition and the other was one that would administer an active air quality management that would achieve the target condition as in the following table. The BAU scenario corresponds to the case where the annual mean PM2.5 concentration is 25 $\mu g/m^3$, whereas the policy scenario corresponds to the case where the annual mean PM2.5 concentration is 15 $\mu g/m^3$. After reading the scenario, the respondents were asked if they were willing to pay a local tax albeit small. To those who responded in the positive, a subsequent question that asked if they were willing to pay a certain amount of money for 5 years as a local tax after the amount was presented. The initial bid was divided into five different values of an annual amount per household ranging from 45 US dollar (or 50,000 Korean won) to 227 US dollar (or 250,000 Korean won) with an increment of 45 US dollar (or 50,000 Korean won).[3] Each respondent was presented with a randomly chosen value as an initial bid. To those who responded in the positive to the initial bid, a subsequent bid of double the initial bid was presented. To those who responded in the negative to the initial bid, a subsequent bid of half the initial bid was presented. To the respondents who did not show willingness to pay at the beginning, a subsequent question was asked to identify if the response was a protest bid. Depending on the response, the WTP of the household who did not protest was determined as zero while that of a protest bid was excluded from the analysis sample of the reference model.



Note: '$' refers to the amount of money.

Figure 3 Choice format

[3] The exchange rate is about 1,100 Korean won per 1 US dollar.

Table 1 Scenarios

PM 2.5 Status (concentration)	Good (0~15 ㎍/㎥)	Moderate (16~35 ㎍/㎥)	Bad (36~75 ㎍/㎥)
A. Business as usual	57 days a year (16%)	237 days a year (65%)	71 days a year (19%)
B. Policy	183 days a year (50%)	164 days a year (45%)	18 days a year (5%)

Note: A scenario corresponds to the annual mean PM concentration of 25㎍/㎥. B scenario corresponds to the annual mean PM concentration of 15㎍/㎥, estimated from the probability distribution of daily mean PM2.5 concentration of Seoul.

3.2. Statistical Model

The basic model to analyze the WTP is the Spike model suggested by Kristöm (1997). The model is appropriate to reflect WTP responses with a value less than zero. It is not valid to include a negative WTP for those policies that promote public interests such as the policy for the airborne particulate matters management. Therefore, either the conventional logistic model or the probit model, which includes negative answers by definition, would underestimate WTP.

The Spike model of Kriström defines the WTP function as follows.

$$F_{\mathrm{wtp}}(A) = \begin{cases} 0, & \text{if } A < 0 \\ p, & \text{if } A = 0 \\ G_{\mathrm{wtp}}(A), & \text{if } A > 0 \end{cases} \quad (2)$$

where F_{wtp} is the WTP function, G_{wtp} is the cumulative density function satisfying $G_{\mathrm{wtp}}(0) = p$ and $\lim_{A \to \infty} G_{\mathrm{wtp}}(A) = 1$, A is the amount of WTP and p is the ratio of the respondent whose WTP is zero.

If the logistic function is used as a function for G_{wtp}, it is defined as follows:

$$G_{\mathrm{wtp}}(A) = \frac{1}{\{1+\exp(\alpha - \beta A)\}} \quad (3)$$

where α and β are the parameters that can be estimated by maximizing the log-likelihood as in the general logistic model.

Log-likelihood in the Spike model of Kriström (1997) is defined as follows:

$$\ln(L_i) = S_i Y_i \ln\left(1 - F_{\mathrm{wtp}}(A)\right) + S_i(1 - Y_i) \ln\left(F_{\mathrm{wtp}}(A) - F_{\mathrm{wtp}}(0)\right) + (1 - S_i) \ln\left(F_{\mathrm{wtp}}(0)\right) \quad (4)$$

where S takes one if WTP is more than zero and zero if there is no WTP, Y takes one if a presented bid is accepted and zero if declined, and i denotes each respondent.

4. Results and discussions

4.1. Distribution of the respondents by the initial bid

Form the survey, 65.3% of the respondents showed positive WTP, while 29.6% and 5.1% of them were protest bidders and zero-bidders, respectively. As a remark, those who answered 'pays enough tax already' or 'not enough information' were regarded as protest bidders and those who answered 'not affordable to pay' or 'not interested' were regarded as zero bidders as in the literature (KDI, 2012).

The distribution of the respondents by the initial bid is as follows.

Table 2 Distribution of respondents

Initial bid (US dollar a year)	Yes-Yes	Yes-No	No-Yes	No-No	Sum
45	10	30	14	17	71
91	9	33	12	22	76
136	12	19	13	22	66
182	4	21	20	31	76
227	7	15	8	41	71
Sum	42	118	67	133	360

Note: 'Yes-Yes' refers to yes to the first bid and yes to the second bid. Similar meaning for the other cases. The exchange rate 1 US dollar = 1,100 Korean Won.

The ratio of protest bids by socioeconomic characteristics of respondents such as income, gender, and environmental consciousness agrees with the socioeconomic theory as shown in the following table.

Table 3 Multinomial regression results

Character	Relative risk ratio*	Standard error	p-value
Sex of the respondent (Female=0, Male=1)	1.52	0.29	0.028
Age of the respondent**	1.09	0.08	0.233
Household Income***	0.89	0.05	0.022
Willing to purchase a dust protection mask? (No=0, Yes=1)	0.76	0.15	0.156
Support mitigation of emissions (No=0, Yes=1)	0.61	0.09	0.001
Household members_ Children (No=0, Yes=1)	0.91	0.23	0.708
Household members _ Elderly (No=0, Yes=1)	1.12	0.27	0.627
Household members _ Respiratory patient (No=0, Yes=1)	1.46	0.65	0.394
Household members _ Cardiovascular patient (No=0, Yes=1)	0.67	0.35	0.441
Constant	5.41	4.21	0.030

Note: N=551, Log likelihood(LR)=-337.23, LR chi-square (9) = 36.70, p-value < 0.001, Pseudo R-square=0.0516

* Relative risk ratio refers to how much a person with a certain character (group 1 or a unit increase) resists to pay the money for PM management policies, compared to the other case (group 0 or a unit decrease).

** 1 for 20~29, 2 for 30~39, 3 for 40~49, 4 for 50~59, 5 for 60 or more

*** 1 for less than KRW 2 million a month, 2 for KRW 2~3 million a month, 3 for KRW 3~4 million a month, 4 for KRW 4~5 million a month, 5 for 5~6 KRW million a month, 6 for KRW 6 million a month or more. The exchange rate 1 US dollar = 1,100 Korean won (KRW).

4.2. The benefit of particulate matter management policy

The estimation by the Spike model of Kriström (1997) is as follows. The logistic function is applied for the cumulative density function (Equation 3). Except protest bidders, a total of 388 samples are used for the analysis. Annual WTP per household for the management policy of Seoul on the airborne particulate matter is 126 US dollar (or 138,107 Korean won) (95% confidence interval of 114 to 137 US dollar). Considering the total number of household in Seoul, the total WTP of Seoul for the management policy of airborne particulate matter is 492 million US dollar (or 540.7 billion Korean won) annually (95% confidence interval of 446 to 537 million US dollar).

Table 4 Spike model statistics

	Coefficient	Standard error	p-value	95% Confidence interval
β	0.0000156	9.42e-7	<0.001	(0.0000137, 0.0000174)
Constant	2.026832	0.1439092	<0.001	(1.744775, 2.308889)

Note: N=388, Log likelihood (LR) = -374.88, Wald chi-square (1) = 273.20, p-value < 0.001

Alternative models to the Spike model such as the probit model, the logit model and the non-parametric model are also used to estimate WTP. It is to investigate how the estimate of WTP varies depending on the models applied. As presented in the following table, the probit model and the logit model estimate a relatively low WTP than the Spike model with a wider 95% confidence interval. This is because the models by definition allow a negative WTP for the distribution. For a modified method that excludes WTP of less than zero, the truncated logit model is also applied, which estimates double the WTP that estimated by the conventional logit model. Another method that excludes WTP of less than zero, suggested by Haab and McConnel (2002), estimates 102 US dollar, which is less than that from the Spike model. The method suggested by Haab and McConnell (2002) excludes zero bidders whose WTP is zero from the samples. If the protest bids are included in the reference model (Equations 2, 3) as analysis sample, i.e. WTP of the protest bids is treated as zero, the WTP is estimated about 93 US dollar. However, the estimate does not consider that the real benefit of the protest bidders can be higher than zero although they did not show an explicit WTP due to the distrust of the government and so on. As an alternative model that does not assume the WTP function beforehand, the non-parametric model can be applied. The non-parametric model estimates the WTP function solely based on the responses to the questionnaires without assuming a WTP distribution. Since the values presented to the respondents in the questionnaires are not continuous, the cumulative distribution is estimated by the upper limit and the lower limit as in the Appendix C. The lower limit is a method that estimates the cumulative distribution function from the lowest value, while the upper limit is one that estimates the cumulative distribution function from the highest value. The WTP by the lower limit is 91 US dollar, and that by the upper limit is 255 US dollar. Many studies including Carson (2002) apply the lower limit, which is conservative.

Table 5 Alternative models results

Models		WTP (US dollar a year)	95% Confidence interval (US dollar a year)	Notes
Probit model		75	(30, 121)	
Logit model		75	(30, 121)	
Truncated Logit model		156	(111, 202)	Negative or zero WTP truncated
Haab and McConnell (2002) model		102	(66, 137)	
Kriström model 2		93	(81, 104)	Include protest bid as analysis sample
Nonparametric model (turnbull)	Lower	91	-	
	Upper	255		

Note: All models are statistically significant (see Appendix C), Standard errors for the nonparametric model is 6.6. The exchange rate 1 US $ = 1,100 Korean won.

This result is much higher than the estimation made by Kim et al. (2018), which only amounts to an average value of 5 US dollar per year. Although WTP can largely vary depending on the timing and region of survey, this alone cannot explain the vast difference in values between the two studies. As a clarification, the survey by Kim et al. (2018) was conducted in June 2017 with samples selected from the entire country, while this study is based on a survey conducted in June 2018 for citizens of Seoul only. Kim et al. (2018) propose a scenario where the number of days of high concentration episodes would halve within ten years from now, while this study proposes a scenario with an improvement in the number of days with high PM2.5 concentrations within the next 5 years. Another plausible explanation for the disparity between the results of the two studies could be that Kim et al. (2018) only accounts for the improvement in health conditions, while this study also considers the effects of improved visibility. Yin et al. (2018) shows that inclusion of improved visibility tends to increase the total WTP for air pollution controls. Anchoring effect could also provide an explanation for the distinction between the two studies with differences in the offered price range in the survey questionnaire. Kim et al. (2018) propose a price range of 0.9 to 13.6 US dollar, while this study suggest a range between 23 and 155 US dollar, based on the preliminary survey results.

The results of our study is slightly higher than that of Lee et al. (2011), who estimate the WTP of Seoul citizens for various levels of mortality risk reduction due to abatement of PM. The WTP for annual reduction of mortality risk by 1/10,000 was 167 US dollar per person a year in Lee et al. (2011). For the purpose of comparison, the annual reduction of mortality risk from our scenario is about

0.2/10,000.[4] Considering the fact that each household living in Seoul has 2.66 people on average[5] (notice that Lee et al. (2011) investigate WTP per person, while this paper investigates WTP per household) and that the risk reduction level of our scenario is 5 times lower than the one of Lee et al. (2011), we can say that Lee et al. (2011)'s WTP is about 89 US dollar per household a year when the risk reduction level is similar to ours. Put differently, our estimate is 1.4 times higher than the one of Lee et al. (2011). The difference is reasonable in that household income and the level of environmental consciousness especially on particulate matter of the general public has been increased since the year 2007 when the survey of Lee et al. (2011) was conducted.

5. Conclusions

This paper estimates the WTP of the management policy of Seoul on airborne particulate matter using the CV method. The estimated value is an annual WTP of 126 US dollar per household in Seoul (95% confidence interval of 114 to 137 US dollar). Alternative models estimate the WTP ranging from 75 US dollar to 255 US dollar per household annually. Accounting for the number of households, the total benefit of the management policy of Seoul is 492 million US dollar (95% confidence interval of 446 to 537 million US dollar).

The annual budget used for the management of the airborne particulate matter in Seoul is about 146 million US dollar. A simple comparison shows that the benefit of the citizen is 3~4 times higher than the expense used for the management of airborne particulate matter in Seoul. However, a direct comparison between the budget and the benefit is not appropriate since the survey assumed that the PM 2.5 concentration would be 15 $\mu g/m^3$ in 5 years by the management policy. It is not clear that the target can be met with the current expenses that the management policy spends.

The results of this paper are an important basis for the establishment and administration of the management policies on airborne particulate matter in Seoul along with the health effect assessment and the macroeconomic assessment on airborne particulate matters. For an effective administration of the management policies, additional economic analyses are necessary including the sectoral estimation of damage cost and the marginal abatement cost of airborne particulate matter.

<Appendix A> Survey questionnaire

Seoul Metropolitan Government is planning to make a more stringent effort to reduce PM 2.5 concentration in Seoul. With the program, it is expected that the adverse impacts of airborne particulate

[4] For the calculation, we apply the premature death estimates by Han et al. (2018). They estimate that if the annual mean PM2.5 concentration of Seoul is reduced from 24㎍/㎥ to 10㎍/㎥, we can save 1,252 people from the premature death due to PM2.5.

[5] Korean Statistical Information Service (http://kosis.kr).

matters can be mitigated and the visibility of Seoul can be improved. For instance, good days in terms of PM 2.5 concentration will be increased and bad days will be decreased as the following table if the program is implemented. However, the citizen should pay the tax for the program since it takes a lot of money. The program will be administered for the next five years and therefore your family should pay the additional tax annually (identical amount of money each year) for the next five years.

Table A.1. Scenario

PM 2.5 Concentration	Good (0~15 ㎍/㎥)	Moderate (16~35 ㎍/㎥)	Bad (36~75 ㎍/㎥)
A. Business as usual	57 days a year (16%)	237 days a year (65%)	71 days a year (19%)
B. Policy	183 days a year (50%)	164 days a year (45%)	18 days a year (5%)

Q1	If the PM 2.5 concentration is improved from A to B by the stringent program of Seoul, are your family is willing to pay a tax, at least a penny, for the program? The tax is ear-marked for the PM 2.5 control measures such as diesel car policy, reduction of industry emissions, international cooperation. The program is so effective that it is 100 per cent sure that the PM 2.5 concentration of Seoul is improved from state A to state B.

※ Refer to Card 1 for adverse impacts of PM 2.5 on health and visibility

1. Yes → Go to Q1-1
2. No → Go to Q1-4

Q1-1	Is your family willing to pay maximum KRW 50 thousand annually (KRW 4.2 thousand a month) as a tax for the program to be implemented?

※ The annual medical expenditure per person in Korea was KRW 770 thousand in 2016 (excluding national insurance).

※ Refer to Card 2 for the average cost of living in Korea including energy bills in 2018.

1. Yes → Go to Q1-2
2. No → Go to Q1-3

Q1-2	Then, is your family willing to pay maximum KRW 100 thousand annually (KRW 8.3 thousand a month) for the program?

1. Yes
2. No → Go to Q2

Q1-3	Then, is your family willing to pay maximum KRW 25 thousand annually (KRW 2.1 thousand a month) for the program?

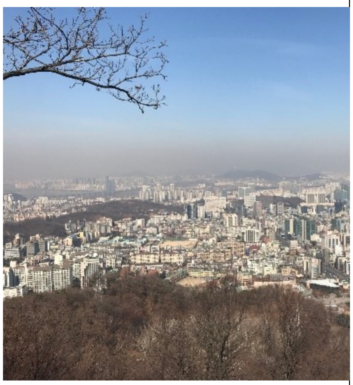
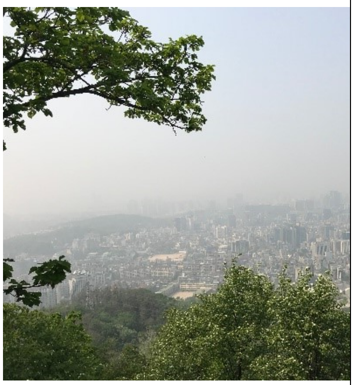
1. Yes
2. No → Go to Q2

Q1-4	Choose the reason why you are not willing to pay the tax?

1. Not able to pay

2. Already paying enough tax
3. Not interested in the issue
4. Not enough information to make a decision
5. Others (   )

<Card 1> The impacts of PM 2.5 concentration

PM 2.5 concentration	Good (0~15 $\mu g/m^3$)	Moderate (16~35 $\mu g/m^3$)	Bad (36~75 $\mu g/m^3$)
Visibility	 (19km)	 (13km)	 (4km)
Health impacts *	Motality risk from respiratory disease decrease 1.8%, Motality risk from cardiovascular disease decrease 1.3%	Motality risk from respiratory disease increase 1.8%, Motality risk from cardiovascular disease increase 1.3%	Motality risk from respiratory disease increase 9.0%, Motality risk from cardiovascular disease increase 6.5%

* Compared to the recent 3-year mean concentration ($25\mu g/m^3$), calculating at the highest concentration level of each range of the level (Good, Moderate, Bad)

<Card 2> Annual cost of living in Korea (2018)

(Unit: KRW/year)

Number of family members	1	2	3	4
Cooking·Heating	226,728	397,008	387,576	381,600
Water Supply·Wastewater	295,668	534,876	729,792	784,584
Electricity	506,148	782,688	923,532	991,944
Other Energy	1,028,544	1,714,572	2,040,900	2,158,128
Maintenance cost of car	-	4,536,000	4,546,800	4,871,400

* Source: Democracy Labor Union (2018)

<Appendix B> General characteristics of respondents

Characteristics	Cases (number)	%
Total respondents	551	100
Gender		

Male	266	48.3
Female	285	51.7
Age		
19~29 yrs	104	18.9
30~39 yrs	106	19.2
40~49 yrs	104	18.9
50~59 yrs	102	18.5
>60 yrs	135	24.5
Household size (persons)		
1	56	10.2
2	113	20.5
3	152	27.6
>4	230	41.7
Monthly household income		
<KRW2,000,000	79	14.3
KRW2,000,000~3,000,000	67	12.2
KRW3,000,000~4,000,000	107	19.4
KRW4,000,000~5,000,000	104	18.9
KRW5,000,000~6,000,000	108	19.6
>KRW6,000,000	86	15.6

<Appendix C> Alternative models

The probit model is as follows.

$$Pr(Y_i = 1|A_i) = \emptyset(\alpha + \beta A_i) \quad \text{(C.1)}$$

where Y is an indicator variable (Y= 1 if the agent is willing to pay A, Y=0 if the agent is not willing to pay), Φ is the cumulative density function of the standard normal distribution, i is household, α, β are parameters. We estimate the parameters so as to maximize the log-likelihood function.

The logit model uses the logistic function instead of the standard normal function in Equation B.1. Haab and McConnell (2002) exclude respondents who are not willing to pay at all (zero bid) as well as protest bid for analysis sample. We apply the logistic function for the model of Haab and McConnell

(2002). Unlike the reference model, we include the protest bid as analysis sample for the Kriström model 2. We apply the turnbull model for the non-parametric estimation, which does not assume the willingness to pay function a prior. The willingness to pay function is estimated from the sampled cumulative distribution function. Considering the sample is discrete we take 2 approaches which use the upper limit and the lower limit, respectively. For more on the models in detail, see Kriström (1997), Haab and McConnell (2002), Carson and Hanemann (2005), KDI (2012).

Table C.1 Probit model results

	Coefficient	Standard error	p-value	95% Confidence interval
β	-3.42e-06	9.15e-07	<0.001	(-5.21e-06, -1.62e-06)
Constant	0.2826392	0.1489808	0.058	(-.0093578, 0.5746363)

Note: N=388, Log likelihood (LR)= -255.89, LR chi-square (1) = 14.12, p-value < 0.001

Table C.2 Logit model results

	Coefficient	Standard error	p-value	95% Confidence interval
β	-5.50e-06	1.49e-06	<0.001	(-8.43e-06, -2.58e-06)
Constant	0.4558958	0.2398741	0.057	(-0.0142489, 0.9260405)

Note: N=388, Log likelihood (LR) = -255.90, LR chi-square (1) = 14.09, p-value < 0.001

Table C.3 Haab and McConell (2002) model results

	Coefficient	Standard error	p-value	95% Confidence interval
β	-6.12e-06	1.56e-06	<0.001	(-9.18e-06, -3.06e-06)
Constant	0.684321	0.2531051	<0.001	(0.188244, 1.180398)

Note: N=360, Log likelihood (LR) = -239.30, LR chi-square (1) = 16.00, p-value < 0.001

Table C.4 Kristrom 2 model results

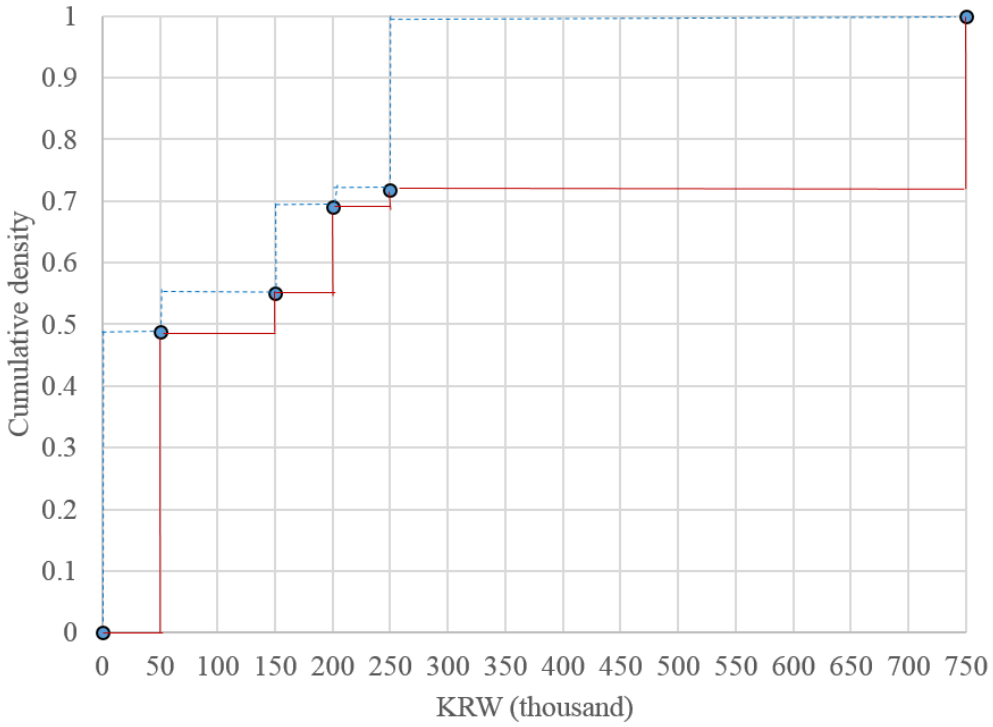
	Coefficient	Standard error	p-value	95% Confidence interval
β	0.00001	6.29e-07	<0.001	(8.81e-06, 0.0000113)
Constant	0.5798771	0.0870074	<0.001	(0.4093458, 0.7504084)

Note: N=551, Log likelihood (LR) = -609.08, Wald chi-square (1) = 255.11, p-value < 0.001

Table C.5 Nonparametric model results

KRW (thousand)	Probability density	Cumulative density	Lower mean (KRW)	Upper mean (KRW)
0		0.000	0	24,375
50	0.488	0.488	3,161	9,484
150	0.063	0.551	21,095	28,127
200	0.141	0.691	5,318	6,648
250	0.027	0.718	70,513	211,538
750	0.282	1.000		
Sum			100,087	280,172

Note: N=388, WTP standard deviation = KRW 7,269, p-value < 0.001, * arbitrarily chosen



Note: the blue dotted line refers to upper limit, the red line refers to the lower limit.

Figure C.1 Cumulative distribution function of WTP

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